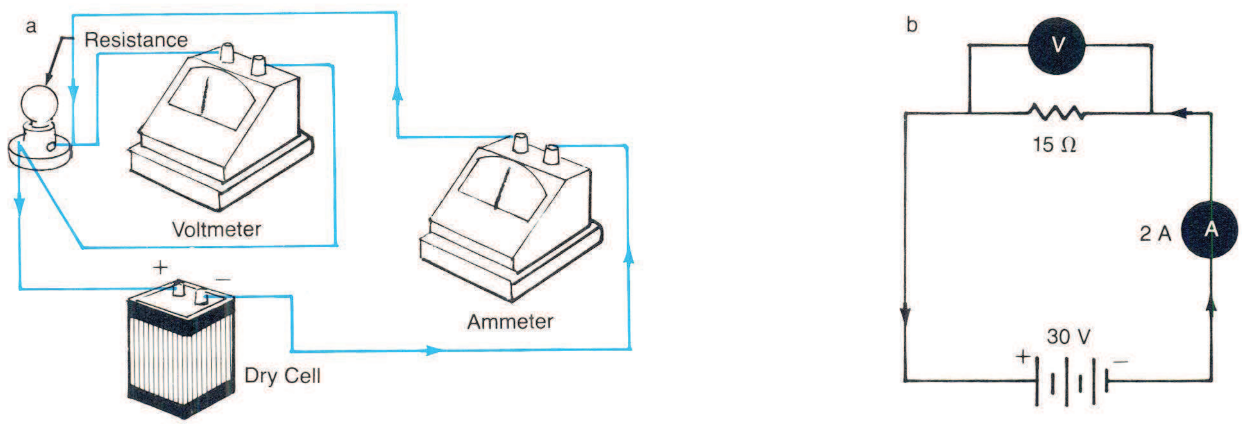


FIGURE 23-6. A simple electric circuit is represented both pictorially (a) and schematically (b).

23:5 Diagramming Electric Circuits

A diagram of an electric circuit often is drawn using symbols for the circuit elements. Such a diagram is called a circuit **schematic.** Some of the symbols are shown in Figure 23-5. Both an artist's drawing and a schematic of the same circuit are shown in Figure 23-6.

A schematic diagram uses symbols for components rather than pictures.

An ammeter, which measures current, must be connected so that all of the electrons can flow through the ammeter. Such a connection is called a **series connection.** A voltmeter measures the potential difference across a circuit element. One voltmeter terminal is connected to one side of the element. The other terminal is connected to the other side. This connection is called a **parallel connection.** The potential difference across the element is equal to the potential difference across the voltmeter.

IR = V
R = V/I

Problems

15. Draw a schematic to show a circuit that includes a 90-V battery, an ammeter, and a resistance of 45 Ω. What is the ammeter's reading?

15. 2 A

16. Draw a circuit diagram to include a 60-V battery, an ammeter, and a resistance of 12.5 Ω. Indicate the ammeter reading.

17. Draw a circuit diagram to include a 16-Ω resistor, a battery, and an ammeter that reads 1.75 A. Indicate the voltage of the battery.

17. 28 V

23:6 Controlling Current in a Circuit

There are two ways to control the current in a circuit. Since $I = V/R$, I can be changed by varying either V, R, or both. Figure 23-7a shows a simple circuit. When V is 60 V and R is 30 Ω, the current flow is 2.0 A.

Current in a circuit can be controlled by changing either the voltage applied or the resistance.

If the current is to be reduced to 1.0 A, the 60-V battery could be replaced with a 30-V battery, Figure 23-7b. The current can also be reduced by increasing the resistance to 60 Ω by adding a 30-Ω resistor to the circuit, 23-7c. Both of these methods will reduce the current to

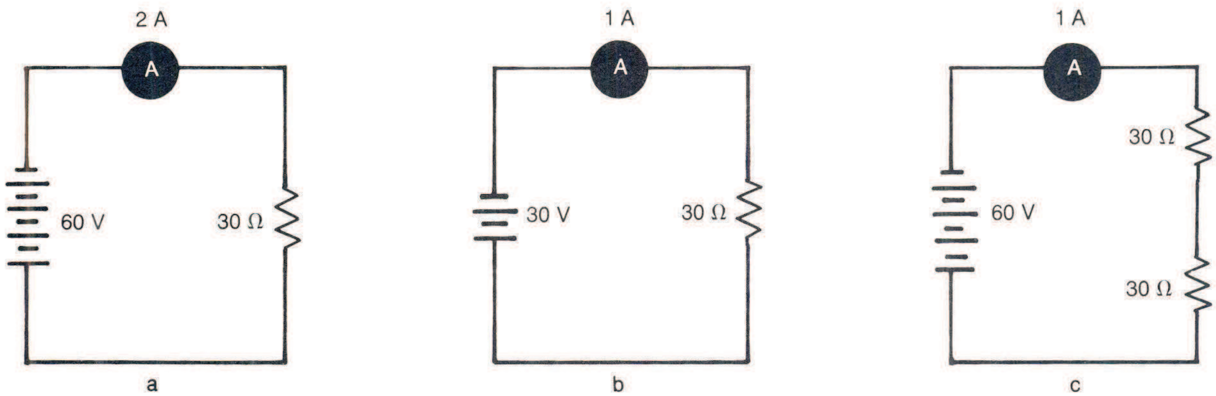


FIGURE 23-7. The current flow through a simple circuit (a) can be regulated by removing some of the dry cells (b) or increasing the resistance of the circuit (c).

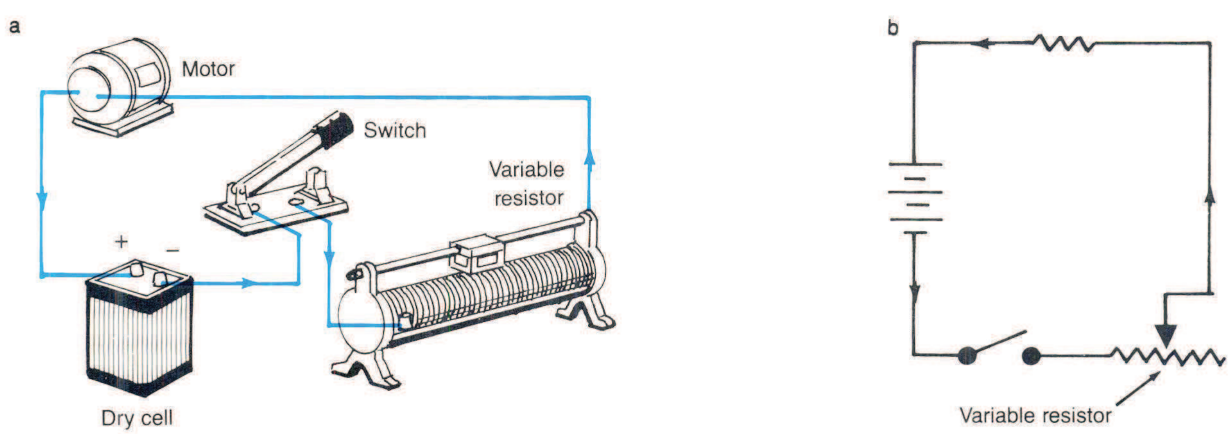
1.0 A. Resistors used to control the current in electric circuits are control resistors. Control resistors are used to allow the proper amount of current through circuits or parts of circuits. Radios use such resistors.

A variable resistor is called a rheostat or potentiometer.

Sometimes a smooth, continuous control of the current is desired. A lamp dimmer allows a continuous rather than step-by-step control of light intensity. To achieve this kind of control, a variable resistor, called a rheostat or **potentiometer**, is used (Figure 23-8). A variable resistor consists of a coil of wire and a sliding contact point. By moving the contact point to various positions along the coil, the amount of wire added to the circuit is varied. With more wire placed in the circuit, the resistance of the circuit increases, and thus the current decreases in accordance with Ohm's law. In this way the light output of a lamp can be adjusted. The same type of device controls the speed of electric fans, electric mixers, and other appliances. To save space, the coil of wire is often bent into a circular shape and the slider is replaced by a knob, as shown in Figure 23-9.

Ohm's law is only valid when the resistance of a device is constant. However, in many materials the resistance increases when the

FIGURE 23-8. A variable resistor can be used to regulate current in an electric circuit.



temperature rises. Light bulb filaments have a much lower resistance when they are cold than when they reach the temperature at which they emit light. As a result of the low resistance when cold, the current through a filament is much higher immediately after the bulb is turned on than the current is only a fraction of a second later. The large current flow causes a rapid increase in temperature. As a result, the filament wire is strained and can break. For this reason, light bulbs often fail as they are switched on, not when they are operating.

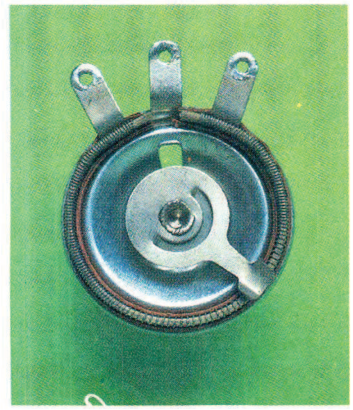


FIGURE 23-9. An inside view of a rheostat.

Problem

18. The current through a lamp connected across 120 V is 0.5 A when the lamp is on.

a. What is its resistance when on?

b. When the lamp is cold, its resistance is one-fifth as large as when the lamp is hot. What is its cold resistance?

c. What is the current through the lamp as it is turned on, if it is connected to a potential difference of 120 V?

23:7 Heating Effect of Electric Currents

The power (energy per unit time) used by an electric circuit is equal to the voltage multiplied by the current. From Ohm's law, we know that $V = IR$. Substituting this expression into the equation for electric power, we obtain

The power varies directly with the resistance.

$$P = VI$$

$$= IR \times I$$

$$\boxed{P = I^2R}$$

The power used by a resistor is proportional to the square of the current that passes through it and to the resistance.

The power used by a resistor varies directly with the square of current flowing through the resistor.

The energy supplied to a circuit can be used in different ways. A motor converts electric energy into mechanical energy. An electric

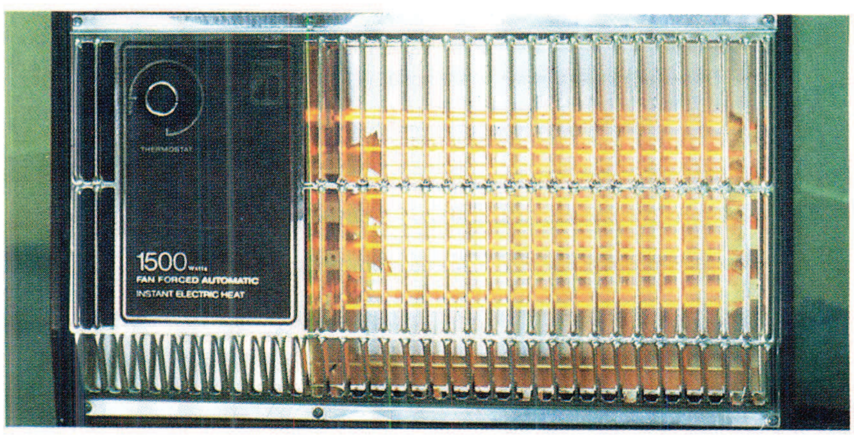


FIGURE 23-10. The coils of this space heater are an example of the conversion of electric energy to thermal energy.

lamp changes electric energy into light. However, not all of the electric energy delivered to a motor or an electric light ends up in a useful form of energy. Some energy is always converted into thermal energy. Certain devices, such as curling irons, are designed to convert most of the electric energy to thermal energy. Some electric energy, as in Figure 23-10, is also converted into light.

The total energy supplied to any device is the product of power and time.

The electric energy transferred to a resistor in a time interval, t, is equal to I^2Rt. If all the electric energy is converted into thermal energy of the resistor, the increase in thermal energy is

$$\boxed{Q = I^2Rt}$$

The resulting high temperature of the resistor can result in heat flowing to a cold substance. For example, in an immersion heater, a resistor placed in a cup of water can bring the water to the boiling point in a few minutes.

EXAMPLE

Thermal Energy Produced by an Electric Current

A heater has a resistance of 10.0 Ω. It operates on 120.0 V. **a.** What is the current through the resistance? **b.** What thermal energy in joules is supplied by the heater in 10.0 s?

Given: $R = 10.0\ \Omega$ **Unknowns:** **a.** I **b.** Q

$V = 120.0\ \text{V}$ **Basic equations:** **a.** $I = \dfrac{V}{R}$

$t = 10.0\ \text{s}$ **b.** $Q = I^2Rt$

Solution: **a.** $I = \dfrac{V}{R} = \dfrac{120.0\ \text{V}}{10.0\ \Omega} = 12.0\ \text{A}$

b. $Q = I^2Rt$

$= (12.0\ \text{A})^2(10.0\ \Omega)(10.0\ \text{s}) = 14\ 400\ \text{J}\ (14.4\ \text{kJ})$

Problems

19. a. 8.0 A
b. 29 000 J
c. 29 000 J

19. A 15-Ω electric heater operates on a 120-V outlet.
- **a.** What is the current through the heater?
- **b.** How much energy is used by the heater in 30.0 seconds?
- **c.** How much heat is liberated by the heater in this time?

20. A 30-Ω resistor is connected to a 60-V battery.
- **a.** What is the current in the circuit?
- **b.** How much energy is used by the resistor in 5 minutes?

21. a. 1.2×10^3 J
b. 4.8×10^3 J

21. A 100.0-W light bulb is 20.0% efficient. That means 20.0% of the electric energy is converted to light energy.
- **a.** How many joules does the light bulb convert into light each minute it is in operation?
- **b.** How many joules of heat does the light bulb produce each minute?

22. The resistance of an electric stove element at operating temperature is 11 Ω.
   a. 220 V are applied across it. What is the current through the element?
   b. How much energy does the element use in 30.0 s?
   c. The element is being used to heat a kettle containing 1.20 kg of water. Assume that 70% of the heat is absorbed by the water. What is its increase in temperature during the 30.0 s?

23. An electric heater is rated at 500 W.
   a. How much energy is delivered to the heater in half an hour?
   b. The heater is being used to heat a room containing 50.0 kg of air. If the specific heat of air is 1.10 kJ/kg · C° (1100 J/kg · C°) and 50% of the thermal energy heats the air in the room, what is the change in air temperature?

23. a. 9×10^5 J
b. 8°C

24. How much energy does a 60.0-W light bulb use in half an hour? If the light bulb is 12% efficient, how much heat does it generate during the half hour?

23:8 Transmission of Electric Energy

The large sources of available energy found at places such as Niagara Falls and Hoover Dam are not usually near areas where electricity is in greatest demand. Accordingly, electric energy often must be transmitted over long distances. Therefore, it is important to accomplish this transfer with as little energy loss as possible.

All wires have some resistance, even though it is small. For example, one kilometer of the large wire used to carry electric current into a home has a resistance of 0.2 Ω. Suppose a farmhouse were connected directly to a power plant 3.5 km away (Figure 23-11). The resistance in

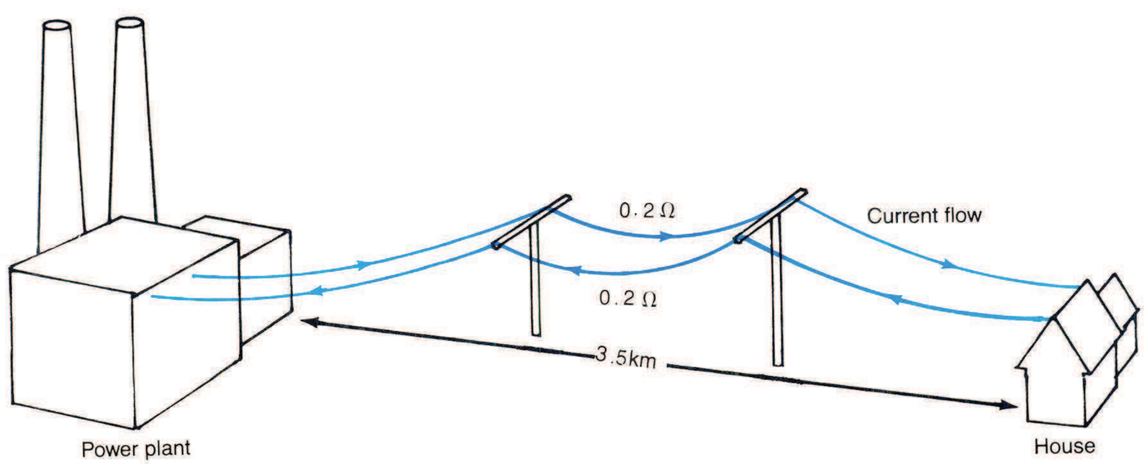
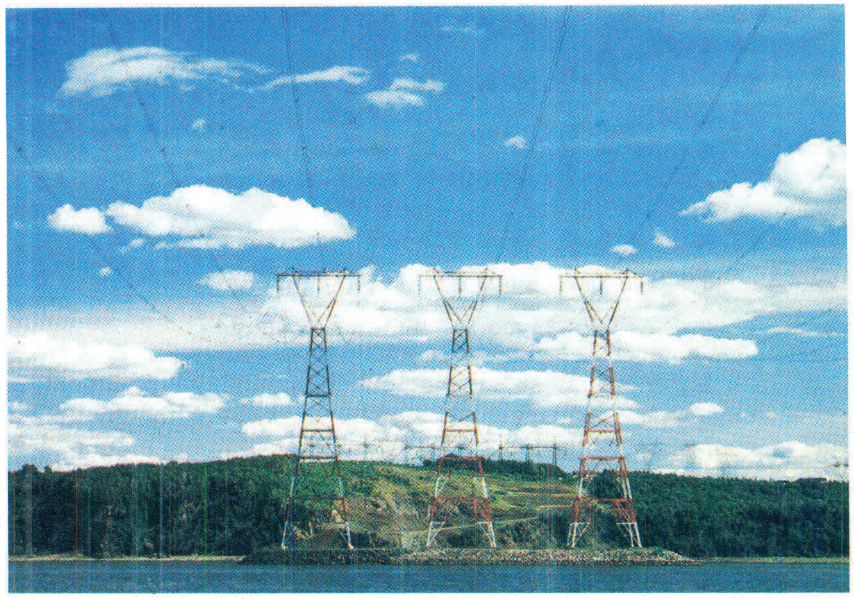


FIGURE 23-11. All wires possess resistance to carrying an electric current.

FIGURE 23-12. High voltage transmission lines carry electricity over long distances.



the wires needed to carry current to the home and back to the plant is 3.5 km × 2 × 0.2 Ω/km = 1.4 Ω. An operating electric stove might cause a 41-A current through the wires. The power lost in the wires is given by $P = I^2R = (41\text{ A})^2 \times 1.4\ \Omega = 2400\text{ W}$. All this power is wasted. This loss is called "I^2R" loss by electrical engineers.

It is to the advantage of power companies and in the interest of consumers to keep the power loss (I^2R loss) in the transmission lines to a minimum. Reducing the I^2R loss is done in two ways. Obviously, the conductors used to transmit electric energy must have the lowest possible resistance. Cables of high conductivity and large diameter should be used. However, since the loss is also proportional to the square of the current in the conductors, it is of even greater importance to keep the current in the lines at a very low value.

High voltage lines are needed to transmit electric power over long distances with minimum energy loss.

The energy per second (power) transferred over a long-distance transmission line follows the relationship $P = VI$. By keeping the voltage across these lines very high, it is possible to transmit large amounts of energy per second and also keep the current in the lines at a low value. This low current reduces the I^2R loss in the lines by keeping the I^2 factor low. Long-distance transmission lines always operate at high voltages to reduce this loss.

23:9 The Kilowatt Hour

While electric companies often are called "power" companies, it is energy that they provide. When you pay your electric bill, you are paying for electric energy, not power.

The electric energy used by any device is its rate of energy consumption in joules per second (watts) times the number of seconds it is operated. Joules per second times second (J/s × s) equals total joules of energy.

The joule is a relatively small amount of energy. For that reason, electric companies measure their energy sales in a large amount of joules called a kilowatt hour, kWh. A **kilowatt hour** is the energy represented by 1000 watts delivered continuously for 3600 seconds, which is one hour. It is, therefore,

$$1 \text{ kWh} = (1000 \text{ J/}\cancel{\text{s}})(3600 \cancel{\text{s}}) = 3.6 \times 10^6 \text{J}$$

A kilowatt hour is an energy unit. It is the rate of energy use (power) multiplied by a time, one hour.

Not many devices in the home other than stoves, heaters, and hair dryers require more than 1000 watts. Ten 100-watt light bulbs operating all at once would use one kilowatt hour of energy if left on for a full hour.

a b

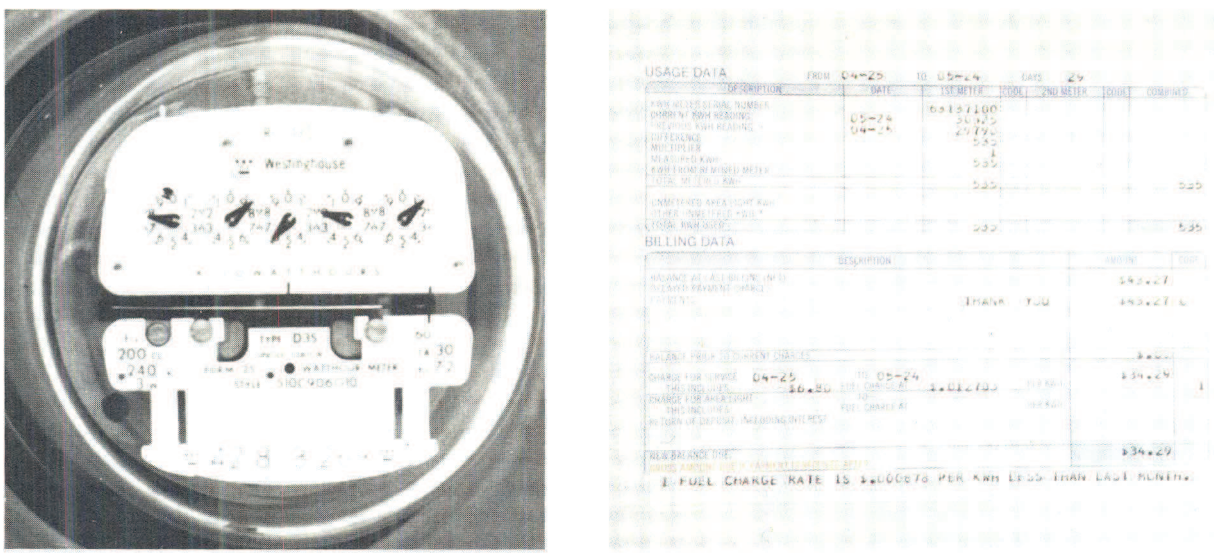


FIGURE 23-13. Watthour meters (a) measure the amount of electric energy used by a consumer. The more current being used at a given time, the faster the horizontal disk in the center of the meter turns. Meter readings are then used in calculating the cost of energy use (b).

EXAMPLE

The Cost of Operating an Electric Device

A new color television set draws 2.0 A when operated on 120 V. **a.** How much power does the set use? **b.** If the set is operated for an average of 7.0 hours per day, what energy in kWh does it consume per month (30 days)? **c.** At $0.08 per kWh, what is the cost of operating the set per month?

Given: $I = 2.0$ A

$V = 120$ V

$t = 2.1 \times 10^2$ h (7.0 h/d × 30 d)

Unknowns: **a.** P **b.** W

Basic equation: $P = VI$

Solution:

a. $P = VI$
$= (120\ V)(2.0\ A)$
$= 2.4 \times 10^2\ W$

b. $W = Pt$
$= (2.4 \times 10^2\ W)(2.1 \times 10^2\ h)$
$= 5.0 \times 10^4\ Wh = 5.0 \times 10^1\ kWh$

c. Cost $= (5.0 \times 10^1\ kWh)(\$0.08/kWh) = \$4.00$

Problems

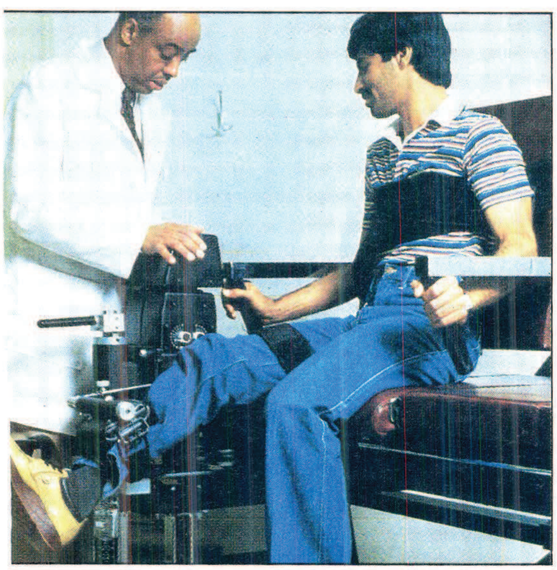
25. a. 1800 W
b. 270 kWh
c. $ 21.60

25. An electric space heater draws 15.0 A from a 120-V source. It is operated, on the average, for 5.0 h each day.
- **a.** How much power does the heater use?
- **b.** How much energy in kWh does it consume in 30 days?
- **c.** At $0.08 per kWh, what does it cost to operate the heater in 30 days?

26. A digital clock has an operating resistance of 12 000 Ω and is plugged into a 115-V outlet.
- **a.** How much current does it draw?
- **b.** How much power does it use?
- **c.** If the owner of the clock pays $0.09 per kWh, what does it cost to operate the clock for 30 days?

Physics Focus

Career–Physical Therapist



A physical therapist or physiotherapist uses a variety of techniques to treat and rehabilitate patients with dysfunction of soft tissues. Treatment includes application of cold, deep heating, surface heating, exercise with or without weights, and surface radiation with ultraviolet light. A physician prescribes treatment.

Therapists administer many forms of heat treatment. Deep heating by short-wave diathermy uses high-frequency AC current to heat tissue beneath the surface. Electromagnetic diathermy also uses AC current, but induces alternating magnetic fields concentrated deep in the body. Ultrasonic diathermy uses high-frequency sound vibrations to reach deep tissues. Surface heating is usually done by conduction from massage, hot pack, or whirlpool.

Direct application of electrical current through the skin to nerves relieves pain by stimulating production of pain-blocking chemicals. Ultraviolet radiation is used to heat the skin and in the treatment of psoriasis.

To rebuild strength, therapists direct patients in exercise programs with weights or special machines.

Physical therapists are trained usually in a five-year program at universities with health-related colleges.